Eur J Vasc Endovasc Surg 33, 518–524 (2007)
doi:10.1016/j.ejvs.2006.12.018, available online at http://www.sciencedirect.com on ScienceDirect

REVIEW

Training for Carotid Intervention: Preparing the Next Generation

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Background. *Carotid interventions are performed to reduce the cumulative risk of stroke. The success of the procedure is dependent upon maintaining low operative risk. This article reviews the current state of training for both carotid endarterectomy (CEA) and carotid angioplasty and stenting (CAS).*
Methods. *Medline searches were performed to identify articles with the combination of the following key words: carotid, endarterectomy, stent, training, assessment and simulation. Manual searches of the reference lists and related papers was conducted.*
Results. *Training and assessment for CEA and CAS follows the traditional apprenticeship model. There is no formal training protocol or objective means of assessment for either carotid endarterectomy or stenting. Models and simulators to allow for training and assessment away from the operative theatre have been developed, and exist for both CEA and CAS.*
Conclusion. *The technology exists to allow for both training and assessment of competency to take place in a controlled and objective environment for both CEA and CAS. The use of simulation needs to be robustly evaluated and assessed to both complement and augment existing training programs to ensure that the highest standards of care are maintained for treatment of carotid territory disease. Objective competency based training and assessment is no longer unattainable. Simulators augment this process and without them operative exposure is sporadic and crisis management infrequent.*

Keywords: Carotid endarterectomy; Carotid stenting; Training; Assessment; Technical Skills.

Introduction

Since the first surgical carotid interventions to prevent stroke, carotid endarterectomy (CEA) has become an evidence based mainstay for the prevention and treatment of stroke.[1,2] The publication of several robust randomised control trials has ratified the position of CEA in the treatment of both symptomatic and asymptomatic disease.[3–5] In recent years the development of carotid angioplasty and stenting (CAS) has increased the potential treatment options available.[6–8] Clearly both these interventions require impeccable technique.[9]

The change in practice bought about by the 'New Deal for Junior Doctors and the European working Time Directives (EWTD)[10–12] has been accompanied by increased scrutiny and demand for objective assessment of technical ability.[11,13] There has also been a move away from the traditional apprenticeship model of surgical training with an emphasis on competency based assessment and training.[14]

This paper reviews the current status of training and assessment for CEA and CAS and evaluates available technology that may be applicable to future training and assessment programs.

Methods

An extensive search of relevant literature was undertaken, employing search engines within PubMed (National Library of Medicine, Bethesda, Maryland, US) and the OVID search engine within the MEDLINE database. Key words: carotid, endarterectomy, stent, simulation, training and assessment were used. Further articles were retrieved by manually searching the reference list of relevant papers.

Cognitive Skills – Training

The physician treating carotid occlusive disease needs a broad range of cognitive skills that go beyond the

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technical ability to perform either CEA or CAS. Various publications have emphasised this; outlining a range of-cognitive skills including understanding the underlying pathology, the natural history of the disease, clinical management and a sound anatomical knowledge.[15,16] The importance of cognitive understanding is recognised in both cardiology and neuro-radiology where minimum time periods have been stipulated for the development of a sufficient understanding of all aspects of the disease process including assessment by examination.[17] Connors emphasised that good cognitive training is essential: for example clinicians treating carotid disease using CAS are required to assess diagnostic cerebral angiography. Leape et al noted that there was a wide range of inter-observer variability when experienced cardiologists interpreted diagnostic coronary angiograms for only one variable of ischaemic vascular disease.[18] If this same result is true of interpretation of diagnostic cerebral angiography, the ramifications could be severe.[17] It is therefore vital that sufficient understanding of all aspects of disease management are gained.

Cognitive Skill − Assessment

Currently knowledge of CEA is tested as part of examinations at the end of surgical training in the United Kingdom (FRCS) and the Fellowship of the European Board of Vascular Surgery exam (FEBVS) by traditional viva-voce or case discussion methods. The validity of this assessment is assumed but has not been validated.

Technical Skills − Training

Carotid endarterectomy has traditionally been taught during an operation.

Many authors have argued that this approach is safe[19−22] Their view is contradicted by an audit conducted by the Vascular Society of Great Britain and Ireland (VSGBI) which concluded that seniority of surgeon performing the CEA was an independent risk factor for stroke.[23] This intuitive conclusion is borne out by the VSGBI database (www.vascularsociety.org.uk/docs/nvdr2004.pdf): 85.5% of the 2290 CEA's performed in the UK in 2003-2004 were performed by consultant surgeons. Regional variation in CEA performance is wide with a range of 0 to 15 per 100,000 population.[24−26] These factors suggest that trainees infrequently perform CEA's, may not be exposed to complications requiring shunt placement and may be trained in areas were CEA is rarely performed. These problems are exacerbated by the decreased time for training that have resulted from the changes in working practice.[11,27]

Training for CAS is more difficult with few centres and surgeons currently performing CAS. Local training for CAS has not been established and courses such as the ESVS/Guidant course can only accommodate a few delegates. Guidelines for training and credentialing have been issued by organizations representing surgeons, cardiologists and radiologists.[28,29] There is recognition that proper training strategies must be developed to allow appropriate training and assessment.[15,17] Guidelines for training of CAS can be extrapolated to a certain extent from experience gained by neuro-radiologists in diagnostic cerebral angiography, and cardiologists in invasive coronary procedures.[15,17]

As with CEA, there is evidence to support the conclusion that results for CAS are closely related to experience. In diagnostic cerebral angiography the risk of stroke ranges from 0.3 to 5.7%, but is consistently lower than 1% for experienced interventionalists.[30−35] Two MRI studies of cerebral infarcts following diagnostic cerebral angiography demonstrated that increased fluoroscopic/procedural time and use of multiple catheters were associated with a significant increase in the risk of embolisation.[36,37]

Learning curves

The learning curve for CEA is not clearly established. For CAS there is a learning curve which may be extremely long.[17] In diagnostic cerebral procedures there is a clearly defined learning curve that continues up to 200 procedures, before competence is gained.[33] Cardiologists have stipulated a minimum training period of 20 months of supervised cardiac catheterisations with a minimum of at least 250 supervised coronary stent procedures before a practitioner is deemed competent to perform coronary interventions independently.[38] This is in addition to 24 months core training in cognitive skills and 300 diagnostic coronary angiograms.

Technical Skill − Assessment

Mentor assessment

Mentor based assessment and the traditional apprenticeship model of training have been criticised for lacking objectivity.[11,14,39] This traditional method of evaluating many aspects of a surgeons ability does not afford the accountability required of a modern surgical training and assessment process. Furthermore the reduction in hours imposed by regulatory changes has made this traditional bastion of training more difficult to achieve.

Logbooks

Logbooks have formed the backbone of assessment of technical experience. They provide an ongoing record of the trainees experience and the training provided by the institution. They continue to form part of the accreditation process for entry into the European Board of Vascular Surgery (FEBVS) exams. However logbooks have been shown to have a poor correlation with technical skills performance in this exam,[40] and log book experience may correlate poorly with actual ability.[12,14,41]

Clinical outcome indicators

The clinical outcome for the procedure is the most relevant end-point for evaluation of a procedure. Fortunately very few patients suffer adverse events following CEA and CAS, ironically this makes evaluation of the effect of training on patients difficult but the VSGBI audit has already been alluded to.[15,19,20] Proposals for minimum threshold level for technical success and complications have been suggested for CAS. These would encompass minor and major transient deficits, minor or major reversible stroke, minor or major permanent stroke and death and could then be used to set trigger points for poor outcome.[28] No such guidelines exist for CEA but the VSGBI audit uses funnel plots to expose surgeons with outlying results who are then notified.

Simulation Based Assessment and Training: Options for Structured Training and Assessment of Competency

Simulation based training has gained in popularity in recent years.[13,14,41–44] Simulation has been robustly assessed for procedures such as laparoscopic cholecystectomy[45–47] and sapheno-femoral junction ligation.[13,48,49] Simulations offer the possibility of reducing the learning curve and enabling the trainee to gain both cognitive and technical knowledge in a safe environment away from the patient.

Rating scales/checklists

Global rating scales such as the Objective structured assessment of technical skill (OSATS) and checklists have been shown to provide a valid and robust means of assessment of surgeons.[50,51] Checklists, while popular, may be less reliable than rating scales for assessment of technical skill.[50] Both systems assess various aspects of technical performance such as respect for tissue, instrument handling, needle handling and knowledge of procedure. In addition to these generic measures of skills, task specific rating scales and checklist may provide additional information for objective assessment of a candidate's ability. For CEA these may examine performance of the endarterectomy and shunt placement and for CAS could include features such as wire handling and positioning of the stent and distal protection devices. Procedural scales have, for example, been shown to improve objectivity when assessing sapheno-femoral ligation.[52] These rating scales and checklists can be applied both live and to video footage review.[13,14,41,49]

Bench models

Increasingly sophisticated synthetic bench models have been developed for various procedures. A bench model of a carotid artery containing a plaque has been developed by Limbs & Things (Bristol – United Kingdom) in conjunction with St Mary's Hospital, London, United Kingdom. The steps of the procedure can then be taught and assessed in a safe environment. Sapheno-femoral junction dissection and ligation is the most studied model and shows discriminatory power between surgeons of different grades[52] and correlation with performance in theatre.[14,53] Early results suggest that a synthetic carotid endarterectomy model may allow for skills differentiation and incorporation into a competency based assessment and training program.[54]

End product assessment: a correlate for clinical outcome?

Performance of CEA or CAS on simulators also allows for the evaluation of 'end-product' assessment. Assessment of the 'end-product' produced in simulation has been shown to correlate with technical skill.[13] For CEA the simulated artery can be evaluated for the diameter of the lumen following closure, anastamotic leak rate and accuracy of suture placement. CAS simulators are not yet able to record events such as embolisation but software is being developed to indicate when the vessel wall is damaged by rough wire manipulation, movement of the distal protection device following deployment and accuracy of stent placement (Mentice, Goethenburg, Sweden). We believe that these simulators will allow immediate training feedback and therefore improve technique.

Motion analysis

Motion analysis software measures economy of movement.[55] This has shown early promise in suggesting increasing economy of movement as skill increases.[56] Hand movements can be synchronised with real time video footage.[57,58] Spikes of activity can be reviewed and compared with activity on the video. Measuring economy of movement using these objective measures may allow for monitoring of training and assessment in CEA and CAS.

Endovascular simulators

Simulators are increasingly sophisticated and realistic.[59] A number of companies (Mentice, Sweden; Immersion Corporation, USA; Symbionix, Israel) manufacture endovascular simulators and others are being developed. These systems offer features such as force feedback and the ability to become accustomed to the steps and instruments used in CAS away from the patient. Publications of simulators for CAS are inevitably sparse, however they have demonstrated that use of simulators during a course decreases fluoroscopy time and time to complete a case. Scores as assessed by checklist following training also improve. Furthermore, the trainee is familiarised with the tools required for CAS.[60,61] It is clear from the available literature that while these systems are showing promise they are unlikely to act as a substitute for supervised training on patients. The potential role of simulators is to accelerate the learning curve of familiarity with the instruments and process; simulators cannot replace clinical experience. More studies are needed to assess the value of simulators in reducing the learning curve associated with CAS, and transfer of skill to the operating theatre/angiography suite.

The simulated operating theatre environment

The simulated operating theatre allows for a procedure to be undertaken in an environment as close to reality as possible. All element of a fully functional operating theatre such as staff (nursing, anaesthetic) and equipment are included.[62] The simulated operating theatre allows for assessment of non- technical skills such as communication and decision making[26] which, according to Spencer, are more important than pure technical ability.[63] The simulated operating theatre also allows for the simulation of crisis scenarios.[64] Crises which can be simulated in CEA include complications of general and local anaesthesia, bradycardia and hypotension due to carotid body stimulation, stroke requiring shunt insertion and shunt dislodgement. The trainees can be assessed in a realistic and challenging environment which allows for more robust evaluation of ability than bench models alone.[54]

If the CAS models are used in the simulated operating theatre environment; the realism of these experiences may be further enhanced. The Crossroads Institute in Brussels, has developed a fully functional simulated endoscopy suite which allows for a broad range of interventional vascular procedures to be performed on a sophisticated mannequin.

The simulated operating environment, may allow for further evolution of increasingly sophisticated training away from the operating theatre.

Incorporating models into training

Bench models

These are easily incorporated into a hospital training program. The models can be used in a structured weekly training slot (Fig. 1), and are small enough to be easily moved. They may for example be stored in the operating theatre where the steps of an endarterectomy can be performed while the patient is being anaesthetised, or in the often lengthy wait for the next patient to arrive. In addition trainees can practice in their own time (including at home) and videotape their performance for review at a time that may be more convenient for the trainer.

Endovascular simulators

The cost of the simulators for carotid stenting may prove prohibitive for most vascular units, however

Fig. 1. A weekly training session on a carotid bench model. Performance is being videotaped for later review with the trainee allowing for structured feedback.

Fig. 2. A trainee being instructed on carotid artery stenting on a simulator on a course run during the European Society for Vascular Surgery annual meeting.

several centres offer courses incorporating these simulators. The Crossroads institute in Brussels in collaboration with the European Society for Vascular Surgery incorporate various simulators into training courses (Fig. 2).

Fig. 3. A trainee performing a local anaesthetic carotid endarterectomy in the simulated operating theatre at St Mary's Hospital. The carotid model is attached to the neck of an actor trained to play the role of the patient.

Simulated operating theatre

Not all hospitals have the benefit of a dedicated simulated operating theatre however vacant theatre or empty list may be employed to run simulations (Fig. 3). Courses incorporating the simulated operating theatre are envisaged in the near future.

Conclusion

Current training is dependent upon the vagaries of clinical practice and constrained by the need to provide safe surgery. Crises are infrequent and a trainee cannot, therefore, develop coping mechanisms. Knowledge is tested via written and oral examinations however technical and non-technical aspects of operative performance are not currently tested apart from in the FEBVS exam. The technology for robust training and objective assessment exists and should be developed. It should both complement and augment current training and assessment methods. Objective competency based training and assessment for CEA is no longer unattainable.

References

1 Eastcott HH, Pickering GW, Rob CG. Reconstruction of internal carotid artery in a patient with intermittent attacks of hemiplegia. *Lancet* 1954 Nov 13;**267**(6846):994–996.

2 DeBakey ME. Successful carotid endarterectomy for cerebrovascular insufficiency. Nineteen-year follow-up. *JAMA* 1975 Sep 8; **233**(10):1083–1085.

3 Halliday A, Mansfield A, Marro J, Peto C, Peto R, Potter J *et al.* Prevention of disabling and fatal strokes by successful carotid endarterectomy in patients without recent neurological symptoms: randomised controlled trial. *Lancet* 2004 May 8;**363**(9420): 1491–1502.

4 Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. North American Symptomatic Carotid Endarterectomy Trial Collaborators. *N Engl J Med* 1991 Aug 15;**325**(7):445–453.

5 Randomised trial of endarterectomy for recently symptomatic carotid stenosis: final results of the MRC European Carotid Surgery Trial (ECST). *Lancet* 1998 May 9;**351**(9113):1379–1387.

6 Yadav JS, Wholey MH, Kuntz RE, Fayad P, Katzen BT, Mishkel GJ *et al*. Protected carotid-artery stenting versus endarterectomy in high-risk patients. *N Engl J Med* 2004 Oct 7;**351**(15):1493–1501.

7 Endovascular versus surgical treatment in patients with carotid stenosis in the Carotid and Vertebral Artery Transluminal Angioplasty Study (CAVATAS): a randomised trial. *Lancet* 2001 Jun 2;**357**(9270):1729–1737.

8 Hobson RW. Rationale and status of randomized controlled clinical trials in carotid artery stenting. *Semin Vasc Surg* 2003 Dec; **16**(4):311–316.

9 Vitek JJ, Roubin GS, Al-Mubarek N, New G, Iyer SS. Carotid artery stenting: technical considerations. *AJNR Am J Neuroradiol* 2000 Oct;**21**(9):1736–1743.

10 Wolfe JH. Training–vive la difference? *Eur J Vasc Endovasc Surg* 1999 Jul;**18**(1):1–3.

11 Jackson MJ, Pandey V, Wolfe JH. Training for infrainguinal bypass surgery. *Eur J Vasc Endovasc Surg* 2003 Nov;**26**(5):457–466.

12 Lamont PM, Scott DJ. The impact of shortened training times on the discipline of vascular surgery in the United Kingdom. *Am J Surg* 2005 Aug;**190**(2):269–272.

13 Datta V, Mandalia M, Mackay S, Chang A, Cheshire N, Darzi A. Relationship between skill and outcome in the laboratory-based model. *Surgery* 2002 Mar;**131**(3):318–323.

14 Beard JD, Jolly BC, Newble DI, Thomas WE, Donnelly J, Southgate LJ. Assessing the technical skills of surgical trainees. *Br J Surg* 2005 Jun;**92**(6):778–782.

15 Schneider PA. Optimal training strategies for carotid stenting. *Semin Vasc Surg* 2005 Jun;**18**(2):69–74.

16 Rosenfield K, Babb JD, Cates CU, Cowley MJ, Feldman T, Gallagher A *et al*. Clinical competence statement on carotid stenting: training and credentialing for carotid stenting–multispecialty consensus recommendations: a report of the SCAI/SVMB/SVS Writing Committee to develop a clinical competence statement on carotid interventions. *J Am Coll Cardiol* 2005 Jan 4;**45**(1):165–174.

17 Connors III JJ, Sacks D, Furlan AJ, Selman WR, Russell EJ, Stieg PE *et al*. Training, competency, and credentialing standards for diagnostic cervicocerebral angiography, carotid stenting, and cerebrovascular intervention: a joint statement from the American Academy of Neurology, American Association of Neurological Surgeons, American Society of Interventional and Therapeutic Radiology, American Society of Neuroradiology, Congress of Neurological Surgeons, AANS/CNS Cerebrovascular Section, and Society of Interventional Radiology. *Radiology* 2005 Jan;**234**(1):26–34.

18 Leape LL, Park RE, Bashore TM, Harrison JK, Davidson CJ, Brook RH. Effect of variability in the interpretation of coronary angiograms on the appropriateness of use of coronary revascularization procedures. *Am Heart J* 2000 Jan;**139**(1 Pt 1): 106–113.

19 Bradbury AW, Brittenden J, Murie JA, Jenkins AM, Ruckley CV. Supervised training in carotid endarterectomy is safe. *Br J Surg* 1997 Dec;**84**(12):1708–1710.

20 Naylor AR, Thompson MM, Varty K, Sayers RD, London NJ, Bell PR. Provision of training in carotid surgery does not compromise patient safety. *Br J Surg* 1998 Jul;**85**(7):939–942.

21 Padayachee TS, McGuinness CL, Modaresi KB, Arnold JA, Taylor PR. Value of intraoperative duplex imaging during supervised carotid endarterectomy. *Br J Surg* 2001 Mar;**88**(3): 389–392.

22 Pai M, Handa A, Hands L. Adequate vascular training opportunities can be provided without compromising patient care. *Eur J Vasc Endovasc Surg* 2002 Jun;**23**(6):524–527.

23 McCollum PT, da SA, Ridler BD, de CL. Carotid endarterectomy in the U.K. and Ireland: audit of 30-day outcome. The Audit Committee for the Vascular Surgical Society. *Eur J Vasc Endovasc Surg* 1997 Nov;**14**(5):386–391.

24 Gibbs RG, Newson R, Lawrenson R, Greenhalgh RM, Davies AH. Diagnosis and initial management of stroke and transient ischemic attack across UK health regions from 1992 to 1996: experience of a national primary care database. *Stroke* 2001 May; **32**(5):1085–1090.

25 Gibbs RG, Todd JC, Irvine C, Lawrenson R, Newson R, Greenhalgh RM *et al*. Relationship between the regional and national incidence of transient ischaemic attack and stroke and performance of carotid endarterectomy. *Eur J Vasc Endovasc Surg* 1998 Jul;**16**(1):47–52.

26 Moorthy K, Munz Y, Adams S, Pandey Y, Darzi A. Human factors analysis of technical and team skills during procedural simulations. 90 ed. 2004. p. 88–89.

27 Wolfe JH. General surgical training–improvements and problems. Vascular Advisory Committee of the Vascular Surgical Society of Great Britain and Ireland. *Ann R Coll Surg Engl* 1998 May;**80**(3 Suppl):112–116.

28 Barr JD, Connors III JJ, Sacks D, Wojak JC, Becker GJ, Cardella JF *et al*. Quality improvement guidelines for the performance of cervical carotid angioplasty and stent placement. *AJNR Am J Neuroradiol* 2003 Nov;**24**(10):2020–2034.

29 Creager MA, Goldstone J, Hirshfeld Jr JW, Kazmers A, Kent KC, Lorell BH *et al*. ACC/ACP/SCAI/SVMB/SVS clinical competence statement on vascular medicine and catheter-based peripheral vascular interventions: a report of the American College of Cardiology/American Heart Association/American College of Physician Task Force on Clinical Competence (ACC/ACP/SCAI/SVMB/SVS Writing Committee to develop a clinical competence statement on peripheral vascular disease). *J Am Coll Cardiol* 2004 Aug 18;**44**(4):941–957.

30 Heiserman JE, Dean BL, Hodak JA, Flom RA, Bird CR, Drayer BP *et al*. Neurologic complications of cerebral angiography. *AJNR Am J Neuroradiol* 1994 Sep;**15**(8):1401–1407.

31 Mani RL, Eisenberg RL. Complications of catheter cerebral arteriography: analysis of 5,000 procedures. II. Relation of complication rates to clinical and arteriographic diagnoses. *AJR Am J Roentgenol* 1978 Nov;**131**(5):867–869.

32 McIvor J, Steiner TJ, Perkin GD, Greenhalgh RM, Rose FC. Neurological morbidity of arch and carotid arteriography in cerebrovascular disease. The influence of contrast medium and radiologist. *Br J Radiol* 1987 Feb;**60**(710):117–122.

33 Dion JE, Gates PC, Fox AJ, Barnett HJ, Blom RJ. Clinical events following neuroangiography: a prospective study. *Stroke* 1987 Nov;**18**(6):997–1004.

34 Grzyska U, Freitag J, Zeumer H. Selective cerebral intraarterial DSA. Complication rate and control of risk factors. *Neuroradiology* 1990;**32**(4):296–299.

35 Johnston DC, Chapman KM, Goldstein LB. Low rate of complications of cerebral angiography in routine clinical practice. *Neurology* 2001 Dec 11;**57**(11):2012–2014.

36 Bendszus M, Koltzenburg M, Burger R, Warmuth-Metz M, Hofmann E, Solymosi L. Silent embolism in diagnostic cerebral angiography and neurointerventional procedures: a prospective study. *Lancet* 1999 Nov 6;**354**(9190):1594–1597.

37 Britt PM, Heiserman JE, Snider RM, Shill HA, Bird CR, Wallace RC. Incidence of postangiographic abnormalities revealed by diffusion-weighted MR imaging. *AJNR Am J Neuroradiol* 2000 Jan;**21**(1):55–59.

38 Hirshfeld Jr JW, Ellis SG, Faxon DP. Recommendations for the assessment and maintenance of proficiency in coronary interventional procedures: Statement of the American College of Cardiology. *J Am Coll Cardiol* 1998 Mar 1;**31**(3):722–743.

39 Reznick RK. Teaching and testing technical skills. *Am J Surg* 1993 Mar;**165**(3):358–361.

40 Pandey VA, Wolfe JH, Liapis CD, Bergqvist D. The examination assessment of technical competence in vascular surgery. *Br J Surg* 2006 Sep;**93**(9):1132–1138.

41 Pandey VA, Wolfe JH, Lindahl AK, Rauwerda JA, Bergqvist D. Validity of an exam assessment in surgical skill: EBSQ-VASC pilot study. *Eur J Vasc Endovasc Surg* 2004 Apr;**27**(4):341–348.

42 Datta V, Mandalia M, Mackay S, Darzi A. The PreOp flexible sigmoidoscopy trainer. Validation and early evaluation of a virtual reality based system. *Surg Endosc* 2002 Oct;**16**(10): 1459–1463.

43 Bann S, Khan MS, Datta VK, Darzi AW. Technical performance: relation between surgical dexterity and technical knowledge. *World J Surg* 2004 Feb;**28**(2):142–146.

44 Bann S, Datta V, Khan M, Darzi A. The surgical error examination is a novel method for objective technical knowledge assessment. *Am J Surg* 2003 Jun;**185**(6):507–511.

45 Eriksen JR, Grantcharov T. Objective assessment of laparoscopic skills using a virtual reality stimulator. *Surg Endosc* 2005 Jul 28.

46 Korndorffer Jr JR, Dunne JB, Sierra R, Stefanidis D, Touchard CL, Scott DJ. Simulator training for laparoscopic suturing using performance goals translates to the operating room. *J Am Coll Surg* 2005 Jul;**201**(1):23–29.

47 Brunner WC, Korndorffer Jr JR, Sierra R, Dunne JB, Yau CL, Corsetti RL *et al*. Determining standards for laparoscopic proficiency using virtual reality. *Am Surg* 2005 Jan;**71**(1):29–35.

48 Moorthy K, Vincent C, Darzi A. Simulation based training. *BMJ* 2005 Mar 5;**330**(7490):493–494.

49 Beard JD. Setting standards for the assessment of operative competence. *Eur J Vasc Endovasc Surg* 2005 Aug;**30**(2):215–218.
50 Martin JA, Regehr G, Reznick R, MacRae H, Murnaghan J, Hutchison C *et al*. Objective structured assessment of technical skill (OSATS) for surgical residents. *Br J Surg* 1997 Feb;**84**(2): 273–278.
51 Reznick R, Regehr G, MacRae H, Martin J, McCulloch W. Testing technical skill via an innovative ''bench station'' examination. *Am J Surg* 1997 Mar;**173**(3):226–230.
52 Pandey V, Wolfe JH, Moorthy K, Munz Y, Jackson MJ, Darzi AW. Technical skills continue to improve beyond surgical training. *J Vasc Surg* 2006 Mar;**43**(3):539–545.
53 Datta V, Bann S, Beard J, Mandalia M, Darzi A. Comparison of bench test evaluations of surgical skill with live operating performance assessments. *J Am Coll Surg* 2004 Oct;**199**(4): 603–606.
54 Horrocks EJ, Black SA, Pandey VA, Harrison RH, Wetzel CM, Nestel D *et al*. *Br J Surg* 2006;**93**(Suppl 2):37.
55 Datta V, Mackay S, Mandalia M, Darzi A. The use of electromagnetic motion tracking analysis to objectively measure open surgical skill in the laboratory-based model. *J Am Coll Surg* 2001 Nov;**193**(5):479–485.
56 Datta V, Chang A, Mackay S, Darzi A. The relationship between motion analysis and surgical technical assessments. *Am J Surg* 2002 Jul;**184**(1):70–73.
57 Dosis A, Bello F, Moorthy K, Munz Y, Gillies D, Darzi A. Real-time synchronization of kinematic and video data for the comprehensive assessment of surgical skills. *Stud Health Technol Inform* 2004;**98**:82–88.
58 Dosis A, Aggarwal R, Bello F, Moorthy K, Munz Y, Gillies D *et al*. Synchronized video and motion analysis for the assessment of procedures in the operating theater. *Arch Surg* 2005 Mar; **140**(3):293–299.
59 Gallagher AG, Cates CU. Virtual reality training for the operating room and cardiac catheterisation laboratory. *Lancet* 2004 Oct 23;**364**(9444):1538–1540.
60 Hsu JH, Younan D, Pandalai S, Gillespie BT, Jain RA, Schippert DW *et al*. Use of computer simulation for determining endovascular skill levels in a carotid stenting model. *J Vasc Surg* 2004 Dec;**40**(6):1118–1125.
61 Dayal R, Faries PL, Lin SC, Bernheim J, Hollenbeck S, DeRubertis B *et al*. Computer simulation as a component of catheter-based training. *J Vasc Surg* 2004 Dec;**40**(6):1112–1117.
62 Aggarwal R, Undre S, Moorthy K, Vincent C, Darzi A. The simulated operating theatre: comprehensive training for surgical teams. *Qual Saf Health Care* 2004 Oct;**13**(Suppl 1):i27–i32.
63 Spencer FC. Teaching and measuring surgical techniques-the technical evaluation of competence. 63 ed. 1978. p. 9–12.
64 Moorthy K, Munz Y, Forrest D, Pandey V, Undre S, Darzi A. Human factor analysis of cricis management skills among surgical trainees during a simulated crisis event. 91 ed. 2004. p. 19.

Accepted 18 December 2006
Available online 12 February 2007